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BEACH AND NEARSHORE PROCESSES IN SOUTHEASTERN FLORIDA,(U)
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# (6) BEACH AND NEARSHORE PROCESSES IN SOUTHEASTERN FLORIDA

by

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## ABSTRACT

A 4.5-year series of daily and weekly littoral environment observations and beach profile surveys was made at 3 localities in southeastern Florida. As a result of varying protection by the Bahamas Banks, the amount of wave energy reaching the shoreline decreases from north to south. Mean annual breaker height decreases from a maximum of 2.8 ft at Jupiter on the north to a minimum of 1.6 ft at Hollywood on the south. A pronounced seasonal variation is evident with waves and currents from the northeasterly sector dominating during October through March and from the southeasterly sector dominating during April through September. Monthly averages of breaker height and period data were the same for a 4.5-year set of daily observations and a subset of weekly observations. Potential gross longshore transport rates, estimated using these wave data, ranged from 2,300,000 $yd^3$/yr at Jupiter to 400,000 $yd^3$/yr at Hollywood. The magnitude of beach changes decreased from north to south and was low compared to changes on more exposed beaches on the U.S. east coast. Contributing factors include the sheltering effect of the Bahamas Banks, the lack of significant storms, and the underlying coquina limestone which characteristically crops out just below the MSL shoreline at the two sites with the highest waves, forming a protective reef that effectively retards beach erosion. Beach width and sand volume were highest during the summer months at two of the localities (Jupiter and Hollywood), but were highest during the winter months at one locality (Boca Raton). Seasonal beach changes were two to three times greater than year-to-year changes. The average unit volume change above MSL was -0.71 $yd^3$/ft/yr at Jupiter, + 0.89 $yd^3$/ft/yr at Boca Raton, and -0.04 $yd^3$/ft/yr at Hollywood. Corresponding MSL-shoreline migration rates were -0.4 ft/yr at Jupiter, +1.5 ft/yr at Boca Raton, and -2.9 ft/yr at Hollywood.

## INTRODUCTION

From January 1969 through June 1973 Florida Ocean Sciences Institute, Inc. (FOSI) collected data on beach changes and littoral processes at three southeastern Florida coastal localities under contract with the U.S. Army Coastal Engineering Research Center (CERC).

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The study was carried out as part of CERC's Beach Evaluation Program. The purposes of the study were to accumulate, in a systematic fashion, information regarding winds, waves, and currents in the nearshore environment; and to relate these factors to observed changes in beach profiles along Florida's southeastern coast. A total of 4,898 beach profile surveys and 1,560 littoral environment observations were collected at the beaches of Jupiter, Boca Raton, and Hollywood, Florida (Figure 1).

This report summarizes the data and presents the results of their analysis. The littoral environment parameters analyzed include wind, wave, and longshore current observations. The beach profile variables analyzed include: (1) the sand level changes on surveyed beach profile lines; (2) the horizontal translation of the mean sea level (MSL) shoreline; (3) the volumetric changes above the MSL shoreline; and (4) the volumetric changes below MSL, to a distance offshore of 500 ft at Boca Raton. Correlations are drawn between the environmental parameters and the observed beach changes. A more thorough discussion of the study may be found in Richter (1974) and DeWall (in press).

## STUDY AREA

From north to south the three sites are increasingly protected by the wave shadow of the Bahamas Banks. The beaches are composed of medium to coarse shelly sand, and are underlain by coquina of similar texture and composition. This coquina, which is generally identified as the Anastasia Formation (Pleistocene), is characteristically exposed in the intertidal and inshore zones at Jupiter and Boca Raton, but is covered with four to six-feet of sand at Hollywood.

The Jupiter site is located 80 miles north of Miami Beach and has a shoreline azimuth of N17°W. The nearest inlet - Jupiter Inlet - is located 1.3 miles to the south. There are no coastal structures in the immediate vicinity of the site. Local interests in the town of Jupiter Island, to the north, have constructed numerous seawalls, sloping revetments, and groins. Beach fill was also placed by the town during 1963-1969 and again during the summer of 1973.

The Boca Raton site is 40 miles north of Miami Beach and 2.5 miles north of Boca Raton Inlet. A section of the dune was leveled and replaced by a seawall during condominium construction immediately to the north of the site. There are no other coastal structures at the site.

Hollywood Beach is 15 miles north of Miami Beach. The entrance channel to Port Everglades, a commercial shipping harbor, is 3.5 miles to the north. Several private homes, about 2,100 ft north of the site, are protected by seawalls and groins.

The beach width at all three sites is approximately 100 ft, with a 1 on 10 slope. Dune elevations at Jupiter and Boca Raton are 20 to 25 feet and 10 feet at Hollywood. The net longshore transport of sand is to the south. Estimated net annual transport rates are 230,000 $yd^3$

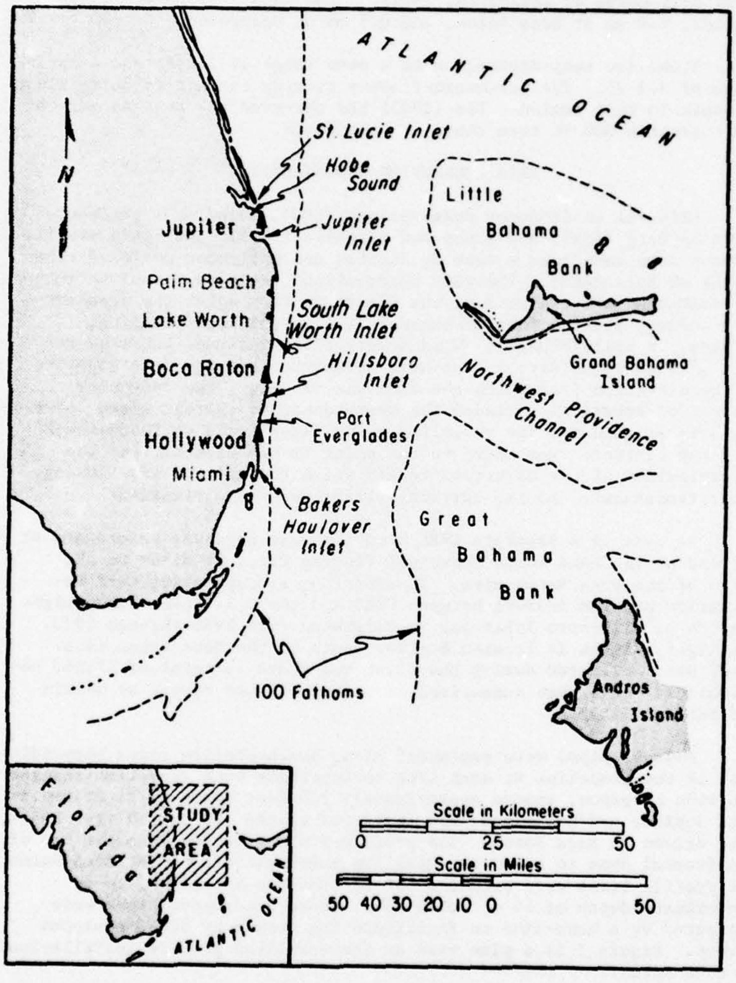


Figure 1. Location Map

at Jupiter, 120,000 $yd^3$ near Boca Raton, and 50,000 $yd^3$ at Hollywood (U.S. Army Corps of Engineers, 1971). Mean sand size is 0.4 mm at Jupiter, 0.6 mm at Boca Raton, and 0.5 mm at Hollywood.

Tides are semi-diurnal, with a mean range of 2.5 ft and a spring range of 3.3 ft. The northward-flowing Florida current is quite close to shore in this region. Lee (1969) has observed the western edge of the current 6,000 ft from shore at Boca Raton.

## DATA COLLECTION AND ANALYSIS

Littoral environment observations (LEO), based on a procedure given by Berg (1968) and Bruno and Hiipakka (1973), and beach profile surveys were made once a week at Jupiter and Hollywood and five times a week at Boca Raton. The surf observations included visual estimates of breaker height and period, the direction from which the breakers were coming, and the type of breaker (i.e., spilling, plunging, surging, or spill/plunge). Wind observations included the measurement of wind speed with a hand-held anemometer and the determination of the direction from which the wind was blowing. The longshore current observations included the measurement of current speed between the breaker zone and the shoreline using fluorescein or rhodamine-B dye, the distance from shore to the point of measurement, and the determination of the direction toward which the current was flowing. Water temperature and rip current spacing were also recorded.

As part of a separate CERC study, a wave gage was maintained at the end of the Lake Worth Municipal Fishing Pier, 16 miles to the north of the Boca Raton site. In addition, a cooperative surf observation program (COSOP) between CERC and the U.S. Coast Guard Light Station at Hillsboro Inlet was in existence from 1955 through 1973. The light station is located 8 miles south of the Boca Raton site. COSOP data collected during the first ten years (a total of 17,940 observations) have been summarized in an unpublished report by Galvin and Seelig (1969).

Rows of pipes were emplanted along beach profile lines perpendicular to the coastline at each site to determine sand elevation changes. Two rows of pipes, spaced approximately 250 feet apart, were driven at both Jupiter and Hollywood, and four rows spaced 100 to 250 feet apart, were driven at Boca Raton. The profile lines extended from the toe of the frontal dune to below the mean low water elevation. At Boca Raton the profile lines were extended 500 ft from the shoreline, to an approximate depth of 15 ft below MSL. These subaqueous pipes were connected by a hand-line to facilitate the survey by SCUBA-equipped divers. Figure 2 is a plan view of the completed profile installation at Boca Raton.

Beach surface elevations relative to mean sea level were determined by measuring the distance between the sand surface and a permanent reference mark on each pipe. The pipe positions and elevations of the reference marks were determined and checked periodically by standard transit and stadia-rod surveying techniques using established bench marks in the vicinity. This technique allowed the rapid

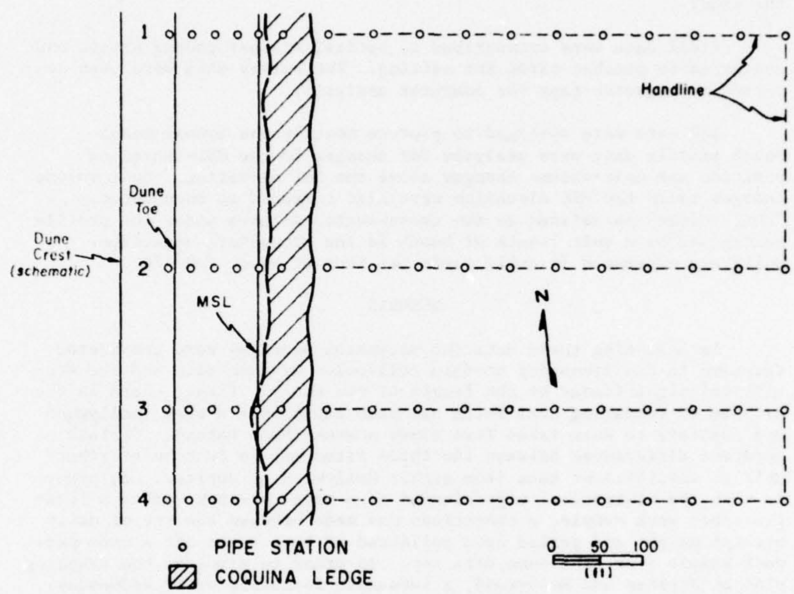


Figure 2. Plan View of Boca Raton Profile Lines

completion of beach surveys by one person using a simple measuring stick.

Pipe positions on the profile lines were determined to an accuracy of ± 0.5 feet. Elevation data were recorded to the nearest 0.5 feet for the first 3 years and to the nearest 0.2 feet for the remainder of the study.

Field data were transcribed to optical-scanner coding sheets and converted to punched cards for editing. The survey data were then converted to magnetic tape for computer analysis.

LEO data were averaged to produce monthly and annual means. Beach profile data were analyzed for changes in the MSL-shoreline position and unit-volume changes above the MSL elevation. Unit volume changes below the MSL elevation were also computed at Boca Raton. "Unit-volume" is defined as the cross-sectional area under the profile multiplied by a unit length of beach in the alongshore direction. Units are expressed in cubic yards per foot of beach ($yd^3/ft$).

## RESULTS

In analyzing these data two potential problems were considered relative to the frequency of data collection at each site and the statistical significance of the length of the study. First, there is the problem of comparing data which has been taken once a week (Hollywood and Jupiter) to data taken five times a week (Boca Raton). Certain apparent differences between the three sites may in fact be attributable to insufficient data from either Hollywood or Jupiter. In order to test the statistical significance of a once-per-week versus a five-times-per week sample, a comparison was made between the set of daily breaker height and period data collected at Boca Raton and a once-per-week sample from that same data set. In order to simulate the sampling plan at Jupiter and Hollywood, a subsample including every Wednesday observation was selected from the Boca Raton data. If no Wednesday observation was made, the closest observation date was selected. This test resulted in a subsample of 229 observations out of a total sample of 1,077 observations. The mean annual breaker height from all Boca Raton observations was 1.96 feet, with a mean standard deviation of 1.36. The height computed from the subsample was 1.97 feet, with a mean standard deviation of 1.42. Average breaker period from the total sample was 4.78 seconds ($\bar{\sigma}$ = 1.36), with 4.80 seconds ($\bar{\sigma}$ = 1.25) computed from the subsample. These values indicate that there is no significant difference between the two data sets, and suggest that comparisons between data collected from the three sites are valid.

A second consideration is the fact that the study was made during an interval of four and a half years in an area where a hurricane can be expected only once in six years and a tropical disturbance only once in three years. Although such storms have not been considered as destructive to the S.E. Florida beaches as winter northeasters, their effect on beaches has not been quantified, and is probably significant. No hurricanes passed within 300 miles of the three sites during the study. A total of three tropical disturbances passed within 50 miles.

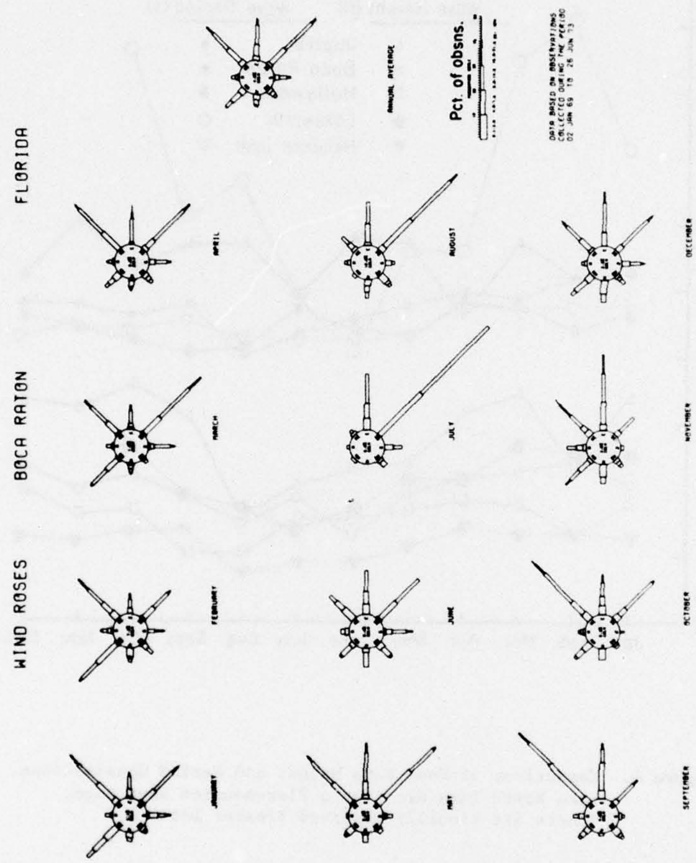


**Figure 3. Mean Monthly and Annual Wind Roses at Boca Raton**

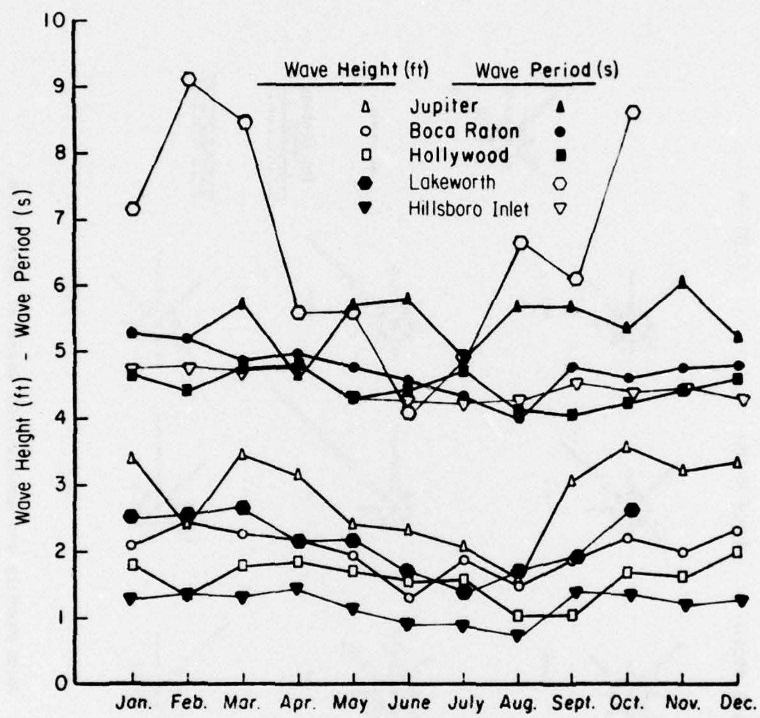


Figure 4. Comparison of Mean Wave Height and Period Observations. Lake Worth Data are from a Pier-mounted Wave Gage, Others are Visually-observed Breaker Data.

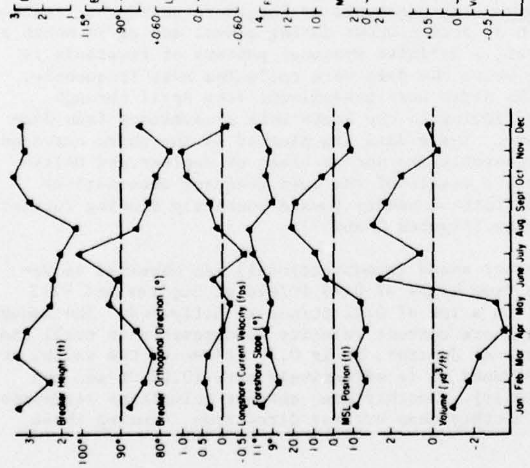


Figure 5.

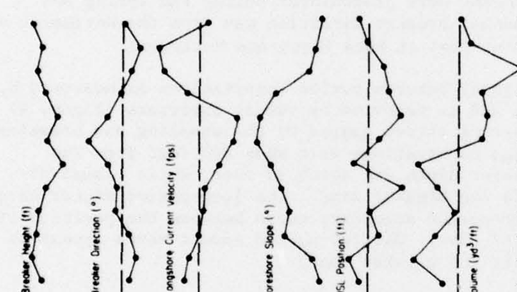


Figure 6.

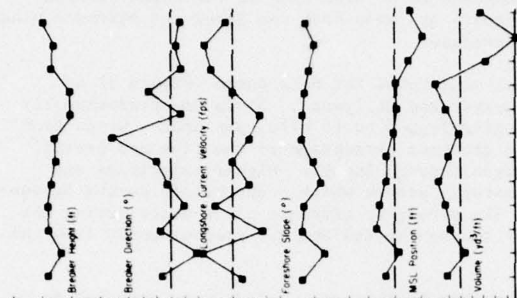


Figure 7.

Monthly Averages of Observations at Jupiter (Figure 5), Boca Raton (Figure 6), and Hollywood (Figure 7).

Winds. Bruno and Hiipakka (1973) have stated that LEO wind data collected in Michigan represent onshore winds more accurately than offshore winds. This is assumed to be also true at the three Florida sites where the measurements are made near sea level and offshore winds are diminished by the foredune.

Monthly and annual wind roses for Boca Raton (Figure 3) are similar to those for Jupiter and Hollywood. Winds are predominantly onshore with speeds ranging from 8 to 15 miles per hour. Winds from the southeast occur the greatest percentage of the time and prevail during the months of March through August. Higher velocities are associated with northeasterly storms which occur mainly during September through February. The strongest offshore winds occur during the winter months (November through March) and are predominantly from the northwest.

Waves. Average breaker heights and periods were observed to decrease from north to south (Figure 4). The highest breakers were generally associated with northeasterlies and occurred during the fall and early winter. As shown in the second curve on Figures 5, 6, and 7, breakers from the southeast were predominant during the spring and summer. The average annual breaker direction was from the Northeast at Jupiter and from the Southeast at Boca Raton and Hollywood.

The large discrepancy between period observations as measured by the gage at Lake Worth and as measured by visual observers (Figure 4) might be due to a filtering effect caused by the shoaling and breaking of incoming waves. Gage observations were made 800 feet from the shoreline, where the water depth was about 18 feet, while visual observations were made in the breaker zone. The long-period winter waves may reform into shorter-period secondary waves between the position of the gage and the breaker zone. Shorter-period summer waves appear to remain more stable up to the breaker zone.

Longshore Currents. Measurements of longshore current velocities show that reversals in direction occur during almost any given month at each locality. However, a definite seasonal pattern of reversals is evident at Boca Raton where the data were collected most frequently. Currents flowing to the north were predominant from April through August while currents flowing to the south were predominant from September through February. These data are plotted as the third curve on Figure 6. Seasonal reversals are not as clear at Jupiter and Hollywood, which is probably a result of the less frequent observations. However, there is a definite tendency toward southerly flowing currents during the winter months (Figures 5 and 7).

The average current speed (nondirectional) was observed to decrease north to south from highs of 0.93 ft/sec at Jupiter and 0.92 ft/sec at Boca Raton, to a low of 0.81 ft/sec at Hollywood. The annual vector sum of all longshore current velocity measurements is small and directed to the south. At Jupiter, it is 0.22 ft/sec to the south, and at Boca Raton and Hollywood it is effectively zero (0.02 ft/sec and 0.01 ft/sec, respectively). Monthly mean current velocities correlate reasonably well with monthly mean breaker directions. During those

months when breakers were approaching from the south of shore-normal, longshore currents generally flowed to the north. During those months when breakers were approaching from the north of shore-normal, longshore currents generally flowed to the south. As the breaker approach angle increased, so did the average current speed.

Longshore Transport Estimates. Using the LEO breaker height and direction data, three methods were compared for calculating the predicted longshore transport rates at each site (Table 1).

The empirical method of Galvin (1972) uses breaker height only and predicts a maximum value for the gross transport rate. The wave energy flux methods, summarized by Das (1972) and the Corps of Engineers (1975, equation 4-40), include the breaker direction and predict gross and net rates. It should be noted that the calculated results are only potential values, based on available wave energy. Other factors, such as limits on the sand supply and protection afforded by the coquina ledge, would be expected to reduce the actual longshore transport rate.

Estimates of gross transport rates using data from this study confirm a trend of decreasing magnitude from north to south. The net transport direction is generally accepted as toward the south at all 3 sites (Column 1). However, the computation of net transport rates (Columns 3 and 4) results in a prediction of transport to the north at Boca Raton and Hollywood. The predicted Hollywood net transport direction is most likely the result of wave refraction around the deep entrance channel at Port Everglades, but may also be the result of the relatively calm weather which prevailed during the study period.

Short-Term Beach Changes. The average volumetric change between the weekly surveys at Jupiter and Hollywood was approximately 1 $yd^3/ft$, with changes slightly greater at Jupiter. The average change between the daily surveys at Boca Raton was 0.5 $yd^3/ft$. Significant short-term changes were generally associated with observed periods of high wave activity, but were not necessarily associated with local storms. Shoreline and volumetric changes associated with three specific storms are listed in Table 2. Negative values indicate erosion. These three storms were the most severe to occur during the study, but were not unusually severe. Winds were typically onshore, averaging 18 to 24 miles per hour, generating breakers averaging 8 to 10 feet in height at Jupiter and Boca Raton and 5 feet at Hollywood. The December 1971 storm was the only time that gale-force winds were observed. In general, each storm caused a net loss at all of the beaches, with the exception of the February 1973 storm at Boca Raton. The change in the shoreline position was not always a reliable indicator of the magnitude of actual beach volume change. In several cases the shoreline change was opposite in sign to the unit-volume change. The magnitude of unit volume changes were comparable to storm changes reported on more exposed U.S. east coast beaches (DeWall, et al. 1977), however, the shoreline changes were smaller.

Seasonal Beach Changes. When the MSL-shoreline position and beach unit volume data are averaged by month, a seasonal trend is

TABLE 1

LONGSHORE TRANSPORT ESTIMATES *

| Locality | (1) Corps of Engineers (1971) | (2) This Study, Using Galvin (1972) | (3) This Study, Using Das (1972) | (4) This Study, Using SPM (1975) |
|---|---|---|---|---|
| Jupiter | | | | |
| gross | | 1,545,680 | 1,459,188 | 2,342,248 |
| net | 230,000 | | 536,592 | 674,027 |
| direc. | S | | S | S |
| Boca Raton | (Hillsboro) | | | |
| gross | | 768,320 | 986,765 | 1,565,017 |
| net | 120,000 | | -10,246 | -14,031 |
| direc. | S | | N | N |
| Hollywood | (Port Everglades) | | | |
| gross | | 492,980 | 416,463 | 628,658 |
| net | 50,000 | | -9,780 | -177,990 |
| direc. | S | | N | N |

* Column (1) estimates are based on impoundment and dredging records, while Columns (2), (3) and (4) are estimates of potential transport which are probably not reached due to underlying coquina (see text). Units are cubic yards per year. (1 $yd^3$/yr = 0.765 $m^3$/yr)

TABLE 2 STORM-INDUCED BEACH CHANGES

| Storm Date | Locality (Profile) | | Survey Dates | MSL Shoreline Change (Ft) | Volume Change Above MSL ($Yd^3/Ft$) |
|---|---|---|---|---|---|
| 24-25 Oct 69 | Jupiter | (1) | 20-27 Oct | -8 | -4.95 |
| ("Laurie") | | (2) | | -14 | -4.96 |
| | Boca Raton | (1) | 23-27 Oct | 0 | 0.00 |
| | | (2) | | -6 | -0.71 |
| | | (3) | | -3 | -1.65 |
| | | (4) | | -2 | -5.42 |
| | Hollywood | (1) | 21-28 Oct | -3 | -1.19 |
| | | (2) | | +5 | +0.34 |
| 22-25 Dec 71 | Jupiter | (1) | 9-30 Dec | +1 | +0.52 |
| | | (2) | | -3 | -3.14 |
| | Boca Raton | (1) | 22-27 Dec | +32 | -0.82 |
| | | (2) | | -22 | -8.01 |
| | | (3) | | -23 | -4.46 |
| | | (4) | | +5 | -0.06 |
| | Hollywood | (1) | 21-28 Dec | -5 | -0.51 |
| | | (2) | | 0 | -0.52 |
| 9-12 Feb 73 | Jupiter | (1) | 9-15 Feb | +11 | -0.24 |
| | | (2) | | -2 | -0.44 |
| | Boca Raton | (1) | 9-12 Feb | +8 | +0.07 |
| | | (2) | | -7 | +0.03 |
| | | (3) | | -2 | +1.23 |
| | | (4) | | -2 | +2.29 |
| | Hollywood | (1) | 6-13 Feb | 0 | -0.17 |
| | | (2) | | 0 | -0.17 |

observed. The bottom two curves in Figures 5, 6, and 7 are the monthly-averaged data, referenced to the mean shoreline position or the mean beach unit volume for each site. At Jupiter and Hollywood the beaches are narrowest in the winter, with the least sand in storage. The beaches at these two sites are rebuilt during the spring. At Boca Raton, just the opposite trend is observed. The beach is widest in the winter, while the maximum beach loss rates occur during the summer months. The seasonal sand volume exchange on and off the beaches decreases from north to south. At Jupiter, approximately 6 $yd^3/ft$ of sand are moved on and off the beach, above MSL, each year. At Boca Raton the seasonal exchange volume is approximately 2 $yd^3/ft$ and at Hollywood it is about 1.5 $yd^3/ft$.

Long-Term Beach Changes. Figures 8, 9, and 10 are monthly averages of the shoreline position and beach unit volume, computed for each year, and referenced to the first survey on each profile line. The plotted regression line is the least-squares fit of the data collected over 4 complete years from January 1969 to January 1973. The partial year of data collected from January through June 1973 was not included in the regression analyses because it was not a complete annual cycle. Table 3 lists the shoreline and above-MSL beach unit

volume changes for each of the 8 surveyed profile lines. The net volume change for the 4 years was a loss of 0.71 $yd^3$/ft/yr at Jupiter, a gain of 0.40 $yd^3$/ft/yr at Boca Raton and essentially zero at Hollywood.

Changes measured on adjacent profile lines were similar in magnitude at Jupiter, but tended to be less similar on the more widely-spaced profile lines at Boca Raton. Changes on the two profile lines at Hollywood were often opposite in sign, which suggests the occurrence of sand waves. This was not directly observed at the site and more

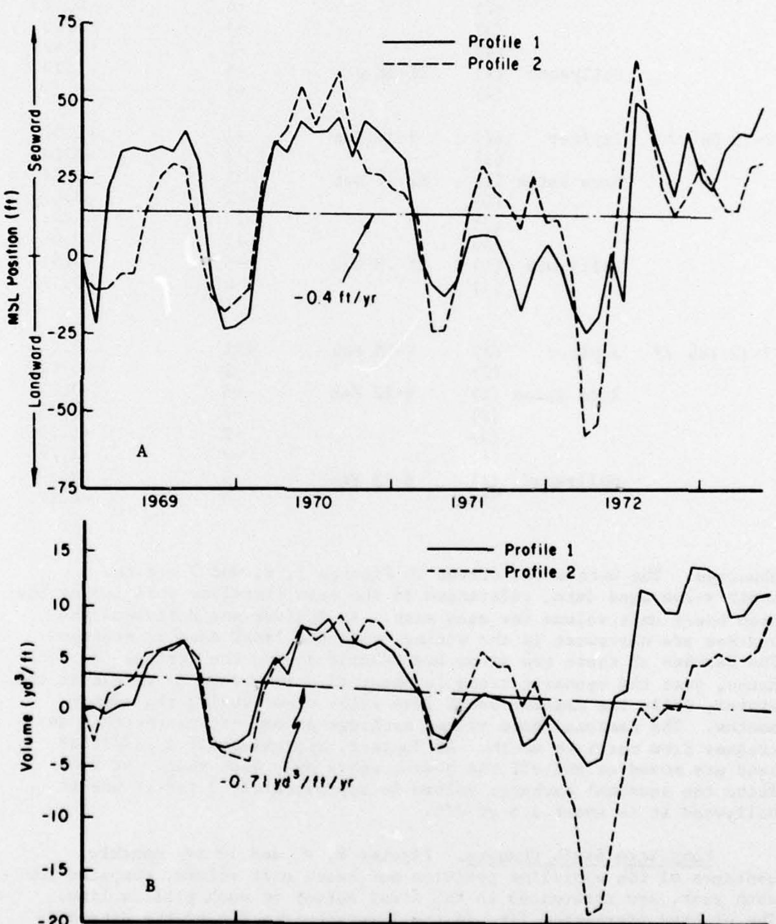


**Figure 8. Mean Monthly Shoreline Position (A) and Unit Volume (B) at Jupiter, Referenced to First Survey.**

than two profile lines are needed to confirm sand wave lengths and direction of movement.

Onshore - Offshore Changes. An objective of this study was to quantify the volume of material transported between the beach and nearshore region. Attempts to correlate unit-volume changes between surveys of the beach with unit-volume changes between surveys of the nearshore at Boca Raton were unsuccessful (DeWall, in press). This may be an indication that sand is moving in an alongshore direction rather than in an onshore-offshore direction. The apparent lack of correlation also suggests that nearshore profile changes are not related to beach profile changes but are related to, or at least dominated by, the migration of nearshore bars in and out of the area being surveyed. In addition, the coquina ledge, which is commonly ex-

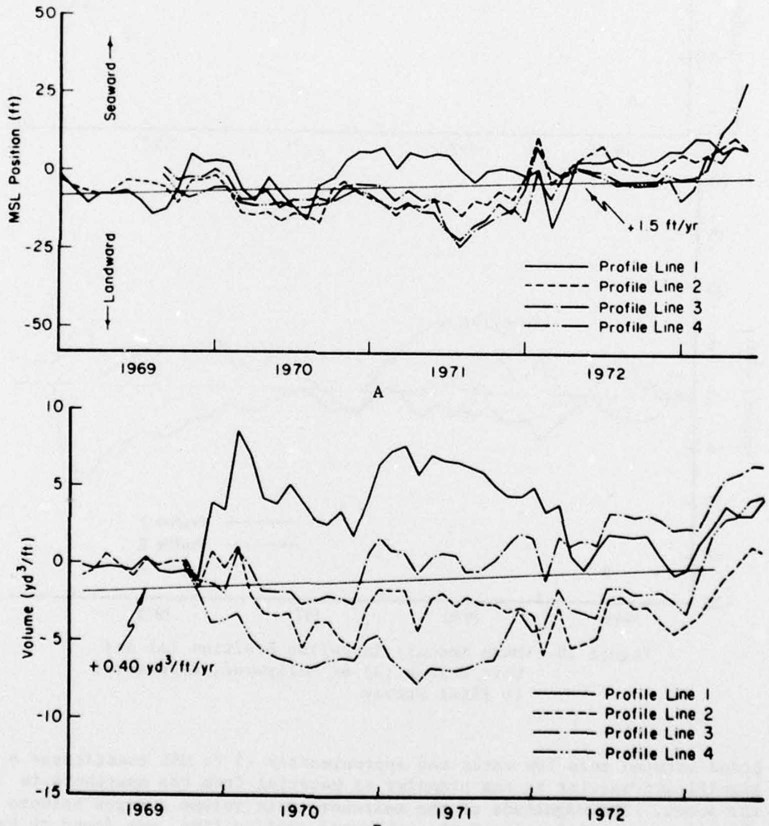


Figure 9. Mean Monthly Shoreline Position (A) and Unit Volume (B) at Boca Raton, Referenced to First Survey.

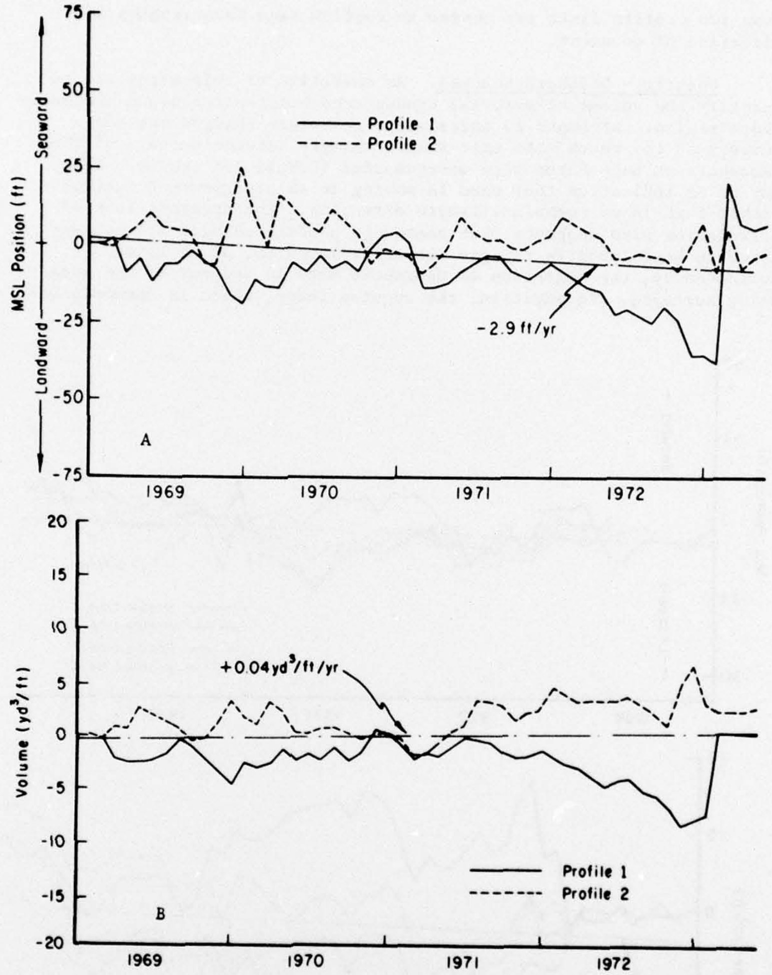


Figure 10. Mean Monthly Shoreline Position (A) and Unit Volume (3) at Hollywood, Referenced to First Survey.

posed between mean low water and approximately -5 ft MSL constitutes a significant barrier to the transfer of material from the nearshore to the beach. The magnitude of the nearshore unit volume changes between surveys, per unit length of the submerged profile line, was found to be of the same order as the unit volume changes on the beach.

TABLE 3

RATES OF BEACH CHANGES FROM 1969 - 1972

| Locality (Profile) | | MSL-Shoreline Change (Ft/Year) | Volume Change Above MSL ($Yd^3$/Ft/Year) |
|---|---|---|---|
| Jupiter | (1) | -0.30 | +0.53 |
| | (2) | -0.42 | -1.97 |
| Boca Raton | (1) | +2.08 | +0.34 |
| | (2) | +2.33 | -0.96 |
| | (3) | -0.37 | +1.44 |
| | (4) | +1.84 | +0.76 |
| Hollywood | (1) | -3.48 | -0.70 |
| | (2) | -2.24 | +0.79 |

## SUMMARY

During the 4-1/2 year period from January 1969 through June 1973 a series of daily and weekly littoral environment observations and beach profile surveys was collected at three locations along the southeast coast of Florida.

The prevailing winds were found to be onshore at speeds ranging from 8 to 15 miles per hour. No hurricanes or major storms occurred during the study period. Gale-force winds were observed only once during the study.

For the three sites investigated there is a systematic measured north-to-south decrease both in the severity of the wave climate, and in the magnitude of beach changes. Breakers averaged 2.8 feet high at an average approach direction from 2.9° to the north of shore-normal at Jupiter. At Boca Raton, breaker height averaged 2.0 feet from a near-normal shoreline approach. At Hollywood, breakers averaged 1.6 feet and approach the shoreline at an average direction from 0.6° to the south of shore-normal. It is concluded that this systematic change is a result of the sheltering effect of the Bahamas.

The lower waves at all three sites occur during the summer months and arrive from the southeast, while the higher waves occur during the winter months and arrive from the northeast. Net longshore current speed and direction is directly related to breaker direction. Breakers approaching from the northeast (winter months) generate currents flowing toward the south, while breakers approaching from the southeast (summer months) generate currents flowing toward the north. Net longshore current speed increases with an increasing breaker angle from the shore-normal approach.

Average annual longshore current speed decreases from a maximum of 0.93 fps at Jupiter, to 0.92 fps at Boca Raton, to 0.81 fps at Hollywood.

Prediction of longshore transport rates at each of the sites, using breaker height and direction data, confirms a previously-published southward decreasing trend. The prediction of net longshore transport rates suggests a null point of convergence between Boca Raton and Jupiter.

All profile lines at Jupiter and Hollywood show a net erosion, as indicated by the MSL-shoreline position. However, one of the two profiles at each of the two sites indicates a net annual gain in unit volume. The net volume change at Jupiter is a loss of 0.71 $yd^3/ft/yr$, while the net change at Hollywood is essentially zero. The profile lines at Boca Raton, on the other hand, indicate accretion - both in shoreline progradation and in beach volume change. The presence of sand waves is suggested by changes on the two Hollywood profile lines.

Beach changes are seasonal at the three localities, but are reversed at Boca Raton. At Jupiter and Hollywood, beaches are narrowest in the winter, with the least amount of sand in storage. At Boca Raton the beach is the widest in the winter, with the greatest amount of sand in storage, while the maximum beach loss rates occur during the summer months. Seasonal beach changes are on the order of two to three times the magnitude of year-to-year changes.

The magnitude of nearshore profile changes at Boca Raton was found to be comparable to the magnitude of the above-MSL beach profile changes. However, the changes on the two sections of the profiles were not found to be directly related. Shore-parallel reefs, and the coquina ledge at and below the MLW-line impede the transfer of sand from the nearshore zone to the beach, but do allow sand to flow from the beach to the offshore zone.

Long-term beach changes measured at the three southeast Florida beaches are relatively small when compared to changes reported for beaches on more exposed coasts (Everts and Czerniak, following paper in this volume). However, storm changes were found to be of a similar magnitude to those reported for more exposed coasts.

## ACKNOWLEDGEMENTS

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Approval for publication is appreciated. The analysis presented in this paper, unless otherwise noted, was based on research conducted at the Coastal Engineering Research Center under the Coastal Engineering Research Program of the U.S. Army Corps of Engineers.

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A 4.5-year series of daily and weekly littoral environment observations and beach profile surveys was made at 3 localities in southeastern Florida. As a result of varying protection by the Bahamas Banks, the amount of wave energy reaching the shoreline decreases from north to south. Mean annual breaker height decreases from a maximum of 2.8 ft at Jupiter on the north to a minimum of 1.6 ft at Hollywood on the south. A pronounced seasonal variation is evident with waves and currents from the southeasterly sector
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dominating during April through September. Monthly averages of breaker height and period data were the same for a 4.5-year set of daily observations and a subset of weekly observations. Potential gross longshore transport rates, estimated using these wave data, ranged from 2,300,000 $yd^3$/yr at Jupiter to 400,000 $yd^3$/yr at Hollywood. The magnitude of beach changes decreased from north to south and was low compared to changes on more exposed beaches on the U.S. east coast. Contributing factors include the sheltering effect of the Bahamas Banks, the lack of significant storms, and the underlying coquina limestone which characteristically crops out just below the MSL shoreline at the two sites with the highest waves, forming a protective reef that effectively retards beach erosion. Beach width and sand volume were highest during the summer months at two of the localities (Jupiter and Hollywood), but were highest during the winter months at one locality (Boca Raton). Seasonal beach changes were two to three times greater than year-to-year changes. The average unit volume change above MSL was -0.71 $yd^3$/ft/yr at Jupiter, +0.89 $yd^3$/ft/yr at Boca Raton, and -0.04 $yd^3$/ft/yr at Hollywood. Corresponding MSL-shoreline migration rates were -0.4 ft/yr at Jupiter, +1.5 ft/yr at Boca Raton, and -2.9 ft/yr at Hollywood.

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